Annual Report
COMPREHENSION OF NAVIGATION DIRECTIONS

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Abstract

Subjects were shown navigation instructions varying in length directing them to move in a space represented by grids on a computer screen. They followed the instructions by clicking on the grids in the locations specified. Some subjects repeated back the instructions before following them, some did not, and others repeated back the instructions in reduced form, including only the critical words. The commands in each message were presented simultaneously for half of the subjects and sequentially for the others. For the longest messages, performance was better on the initial commands and worse on the final commands with simultaneous than with sequential presentation. Instruction repetition depressed performance, but reduced repetition removed this disadvantage. Effects of presentation format were attributed to visual scanning strategies. The advantage for reduced repetition was attributable either to enhanced visual scanning or to reduced output interference. A follow-up study with auditory presentation supported the visual scanning explanation.

(SEE COVER SLIDE.) Our study concerns effects of presentation format and readback on the comprehension and execution of navigation instructions. This work focuses on effective communication in a concrete domain in which it has life-or-death consequences, namely communication between air crews and air traffic controllers. We chose that domain in part because of the success of our earlier research in this area, in which we developed an experimental paradigm analogous to the natural flight situation.

In the usual version of our laboratory task, subjects hear instructions like those given by air traffic controllers; they repeat the instructions aloud, as pilots are expected to do, and then they follow the instructions, navigating in a space displayed on the computer. The instructions describe movements in a grid of four 4 X 4 matrices stacked one on top of another and representing a three-dimensional space, as illustrated on the next slide (SEE SLIDE 1). A sample instruction including three units is: "Turn left two squares; climb down one level; move forward one step." Upon hearing such instructions, the subject immediately repeats them, and, next, to demonstrate comprehension, uses the computer mouse to follow the instructions, by clicking each appropriate square on the grid in the order specified, as shown on the slide.

In the experimental paradigm we have been using and in the standard communication situation, the messages are presented in the auditory modality. The sample message was shown on the slide only for ease of exposition; the subjects did not see the message; they only heard it. However, with new technology (such as the "data link" technologies being explored by NASA and the FAA) the visual modality could be used instead, and the modality used may influence the listeners' ability to comprehend, remember, and carry out the commands in the message. Hence, in a

previous experiment, we compared visual and auditory presentation of messages. We found differences between the two modalities suggesting that subjects had difficulty processing the longer messages in the time allotted when they were presented in the visual modality. The differences we found could be due in part to the fact that all the words were necessarily presented sequentially in the auditory modality but were presented simultaneously in the visual modality, so that subjects given visually presented messages might not have budgeted their time sufficiently well and might have spent too much time on the earlier words, missing the later words. One purpose of the present study was to test this hypothesis by comparing visual messages presented simultaneously and sequentially.

Pilots are required to read back the directions given to them by an air traffic controller. Likewise, in the usual version of our experimental paradigm, the subjects repeat, or read back, the instructions given to them before following them. Although readback plays an important role in terms of verification, some controllers and pilots see the readback procedure as superfluous and time consuming. In fact, there have been voices within the FAA calling for removal of the readback requirement altogether. Thus, it is important to evaluate the effect readback has on performance. In our earlier experiment, we also investigated the role of repeating directions aloud on the execution of these directions by comparing groups in which readback was required to groups in which it was not. We found that the readback requirement led to inferior command execution especially with longer and wordier messages and with messages presented visually. We hypothesized that the negative impact of readback was due to the harmful effects of verbal output interference because the disruption was greatest when verbal output was largest. A second purpose of the present study was to test this hypothesis by comparing full readback

and no readback groups to a reduced readback group, in which output is reduced for the wordier messages. The reduced readback procedure is like that used naturally by pilots, who often repeat back a condensed version of what they hear.

In our first new experiment, subjects were given messages of six different lengths, ranging from one to six commands, with the commands varying in their wordiness, namely, the number of words used for the command. The commands either included redundant four-word statements (for example, "climb down one level") or they included minimal two-word statements (for example, "down one"). The messages involved all three dimensions of movement. In the simultaneous condition, subjects saw the messages presented at the top of the computer screen with one command on each line, as shown on the next slide (SEE SLIDE 2). In our previous study, the visual messages were shown one word per line, but we showed all of the words in a given command on the same line in the present experiment because that presentation format is closer to the one used in NASA's data-link research. In the sequential condition, only one command was shown on the screen at one time, with the commands in the same locations in which they appeared in the simultaneous condition (so the commands "marched" down the screen). Even in the sequential condition, all of the words in a given command were presented at one time, rather than one at a time, to equate the presentation conditions in terms of parsing the commands.

The duration of the visual display was matched to the duration of the auditory presentation in the earlier auditory condition. For example, if a given command took 5 seconds to present aurally, it was shown for 5 seconds in the sequential condition. Likewise, if the entire message took 20 seconds to present aurally, it was shown for 20 seconds in the simultaneous condition. Thus, the

simultaneous and sequential conditions were equated in their overall presentation length. Note that by this procedure the redundant messages were shown for approximately twice as long as the minimal messages because they had twice as many words.

Each subject was given 72 messages arranged in 6 blocks of trials, with 2 messages of each length in each block, one message at each level of command wordiness. The subjects in each presentation condition were subdivided into three groups. Participants in the full readback group were told to repeat aloud all of the directions before following them; those in the no readback group were not told to repeat the instructions; and participants in the reduced readback group were told that they should always repeat back minimal messages even when they saw redundant messages. For example, if they saw "climb up one level," they were to repeat back just "up one."

We tested a total of 48 subjects in this experiment, all of whom were college students and native speakers of English. As summarized on the next slide (SEE SLIDE 3), the experimental design included two between-subjects variables--presentation condition (simultaneous, sequential) and readback group (full readback, no readback, reduced readback)--and two within-subjects variables--message length (1-6), and command wordiness (minimal--2 words, redundant--4 words). The dependent measures were manual movement accuracy in following the directions and (for the full readback and reduced readback groups only) oral repetition accuracy. For these measures, the responses were scored as either completely correct or not correct. In the case of the oral repetition responses, only those words included in the minimal messages were scored even for the full readback group when redundant messages were given and repeated back in full.

The results for the manual movement responses are summarized on the next slide (SEE SLIDE 4) as a function of message length and readback group. As in our previous experiments, we found that accuracy decreased monotonically with increases in message length. Note that, as previously, the largest drop in performance generally occurred between messages of Lengths 3 and 4 and Lengths 4 and 5. Subjects were most accurate when no readback was required and more accurate with the reduced readback than with the full readback, but only with message lengths including three or more commands, because of performance near the ceiling for the shorter message lengths.

Performance on the readback should have been equivalent in the full readback and reduced readback conditions for the minimal messages because the reduction in readback applied only to the redundant messages. In fact, as shown on the next slide (SEE SLIDE 5), the difference between the full and reduced readback conditions was much more evident with the redundant messages than with the minimal messages. The advantage for the reduced readback condition with the redundant messages is a particularly strong result when considering that many (if not all) participants in the full readback condition used some reduced form on at least some of the trials. These trials would not have been marked incorrect on that account because the scoring has always been based on only the two keywords used in the minimal messages. It is also interesting to note that subjects performed better with redundant messages than with minimal messages when either no readback was required or when readback for the two types of messages was in the same reduced format, perhaps because the redundant messages were shown for approximately twice as long. Only when full readback was required was performance worse with redundant messages

than with minimal messages. This finding is consistent with the hypothesis that performance suffers from verbal output interference, which would be larger when more words must be uttered, as in the case of the redundant messages relative to the minimal messages.

In this analysis, we found no effect of presentation format (sequential versus simultaneous) although, as you will see, there are effects of that variable in another analysis.

We also examined the oral repetition responses for subjects in the full readback and reduced readback conditions. These results are summarized on the next slide (SEE SLIDE 6) as a function of message length and readback group. As with the manual movement responses, accuracy decreased monotonically with increases in message length, with the largest drop in performance between messages of Lengths 3 and 4 and Lengths 4 and 5. Again, subjects were more accurate with the reduced readback than with the full readback, but only with message lengths including three or more units, when performance was not on the ceiling.

Although the reduction in readback applied only to the redundant messages, as shown on the next slide (SEE SLIDE 7), the difference between the full and reduced readback conditions was evident for both levels of wordiness but was greater with the redundant messages than with the minimal messages. In our previous experiments, we have found that oral repetition is better on the minimal messages than on the redundant messages, and we have attributed that difference to the increased verbal output interference with redundant messages. However, in the present experiment, the advantage for minimal messages was evident only in the full readback condition, which is the condition we had used

in the past. In the reduced readback condition, performance was actually better for redundant messages than for minimal messages, presumably because the output was equivalent for the two types of messages in that case but the redundant messages were shown for a longer time because of the greater number of words.

As for the manual movement responses, there was no effect of presentation format (sequential versus simultaneous) in this analysis of oral repetition responses. However, we also conducted a set of serial position analyses for the oral repetition responses, and we did find effects of presentation format in those analyses. On the basis of our previous experiment that included a comparison of messages presented in the auditory and visual modality, we had predicted that there would be an interaction of serial position and presentation format, reflecting better performance on the initial positions and worse performance on the later positions for the simultaneous condition relative to the sequential condition. This prediction followed from our hypothesis that subjects poorly allocated their resources when all the commands were shown simultaneously in the visual modality. We did in fact obtain results consistent with this hypothesis.

We conducted separate analyses of the oral repetition responses for each message length because each length has a different number of serial positions. As shown on the next slide (SEE SLIDE 8), there was the expected interaction of presentation format and serial position for both Message Lengths 5 and 6. Performance was better with the simultaneous format than with the sequential format for the initial serial positions but the opposite held for the last two positions. Also note that the serial position functions show a continuous

decrease across positions rather than the typical bow shape, which we attribute to the increasing costs of output interference as subjects repeat back each command in the message.

The serial position analyses on the oral repetition responses also revealed an interesting interaction between readback group and serial position for Messages Lengths 3 to 5, as shown on the next slide (SEE SLIDE 9). There was an increasing advantage of reduced readback relative to full readback as serial position increased. In other words, there was a larger effect of serial position with full readback than with reduced readback. This pattern is consistent with the hypothesis that both the advantage for reduced readback relative to full readback and the declining serial position effect are due to verbal output interference. In addition, as expected because the output for redundant and that for minimal messages are equivalent in the reduced readback condition, the three-way interaction of readback group, serial position, and message wordiness was significant for Message Lengths 3 and 4, which can be seen on the next slide (SEE SLIDE 10). The decline in oral repetition accuracy as serial position increased was largest by far for full readback with the redundant messages.

These findings provide strong confirmation for our previous account of the effects of modality on message comprehension and for the important role of verbal output interference in subjects' ability to repeat back and follow the messages they hear. However, there is an alternative explanation for some of our findings in this experiment involving the comparison of the full readback and reduced readback conditions. It is possible that in the reduced readback condition, subjects developed a scanning strategy in which they ignored the unimportant words in the redundant messages and focused only on the crucial

words that also occurred in the minimal messages. Such a strategy would provide for better performance in the reduced readback condition on the redundant messages relative to the minimal messages because subjects would have more time to study the crucial words. In fact, we did obtain this result for the oral repetition responses, and it would otherwise be difficult to explain because output interference should be equal for the two types of messages with reduced readback. This strategy, though interesting, is specific to the visual modality and could not be employed with the auditory modality. Thus, in our next experiment, we examined the effects of reduced readback with auditorily presented messages.

As shown on the next slide (SEE SLIDE 11), the design of this experiment was just like the last one except there was no distinction between simultaneous and sequential presentation because simultaneous presentation is impossible with the auditory modality. We tested a total of 24 subjects in this experiment.

The results for the manual movement responses are summarized on the next slide (SEE SLIDE 12) as a function of message length and readback group. Again, we found that accuracy decreased monotonically with increases in message length, and the largest drop in performance occurred between messages of Lengths 3 and 4 and Lengths 4 and 5. Unlike our findings with the visual modality in Experiment 1, subjects were not aided by the reduced readback in the present experiment with the auditory modality. In fact, the reduced readback condition showed numerically the poorest performance at the longest message lengths.

Readback should have been equivalent in the full readback and reduced readback conditions for the minimal messages because the reduction in readback

applied only to the redundant messages. However, as shown on the next slide (SEE SLIDE 13), there was no advantage for the reduced readback condition even with the redundant messages.

We also examined the oral repetition responses for subjects in the full readback and reduced readback conditions. These results are summarized on next slide (SEE SLIDE 14) as a function of message length and readback group. As with the manual movement responses, accuracy decreased monotonically with increases in message length, with the largest drop in performance between messages of Lengths 3 and 4 and Lengths 4 and 5. Again, in this experiment, unlike Experiment 1, subjects were numerically less accurate with reduced readback than with full readback at least at the longest message lengths.

Recall that the reduction in readback applied only to the redundant messages, but, as shown on the next slide (SEE SLIDE 15), there was no advantage for the reduced readback even with the redundant messages. As previously, we found that performance on the oral repetition was better on the minimal messages than on the redundant messages, in this case for both the reduced and full readback conditions. As shown on the following slide (SEE SLIDE 16), the advantage for minimal messages was not found, however, for messages at the shortest and longest lengths, where performance is on the ceiling or floor.

In summary, as shown on the next slide (SEE SLIDE 17), although reduced readback had a large facilitating effect when messages were presented visually both with repeating back and executing movements, it gave no advantage for either oral repetition or manual movement responses when messages were presented auditorily, even with redundant messages. Therefore, we conclude

that the advantage for reduced readback is entirely attributable to a visual scanning strategy in which subjects ignored the unimportant words in the redundant messages and focused only on the crucial words that also occurred in the minimal messages. Thus, pilots and others receiving navigation instructions visually might be able to improve their performance by learning optimal scanning strategies. Also, in such cases in which messages are presented visually under time pressure, we offer the caveat that if the commands are presented simultaneously, adequate attention may not be given to the later commands. We cannot extend these recommendations to the auditory modality, but for both modalities our findings strengthen our earlier recommendation to limit navigational instructions to no more than three commands.

Effects of Presentation Format and Repetition on Following Navigation Instructions

by
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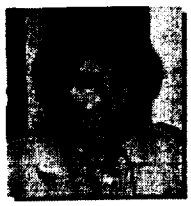
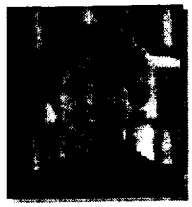


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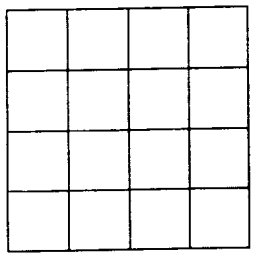
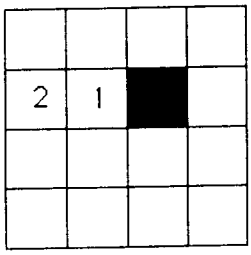


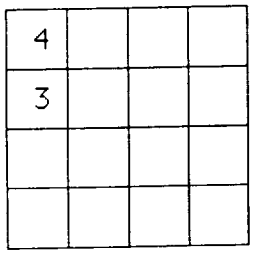
Instructions:

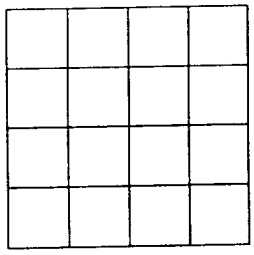
Turn left two squares (1,2)

Climb down one level (3)

Move forward one step (4)



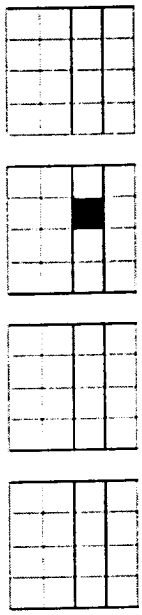




experiment w all lines

turn left one square
climb up one level
move forward one step
turn right two squares

Done

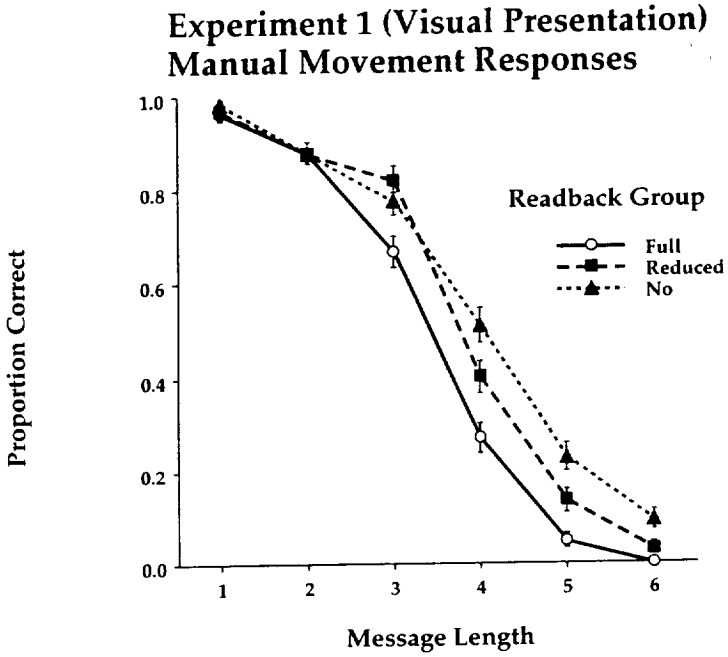


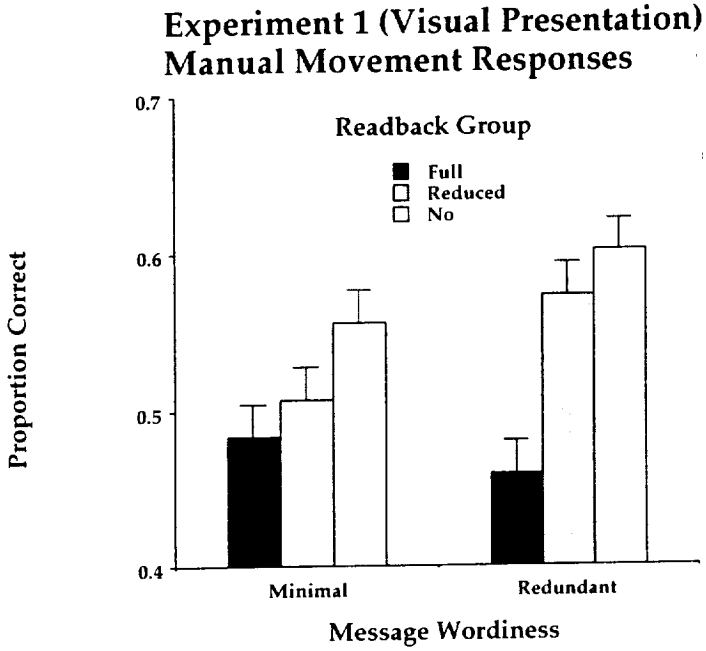
Experiment 1 (Visual Presentation) Design

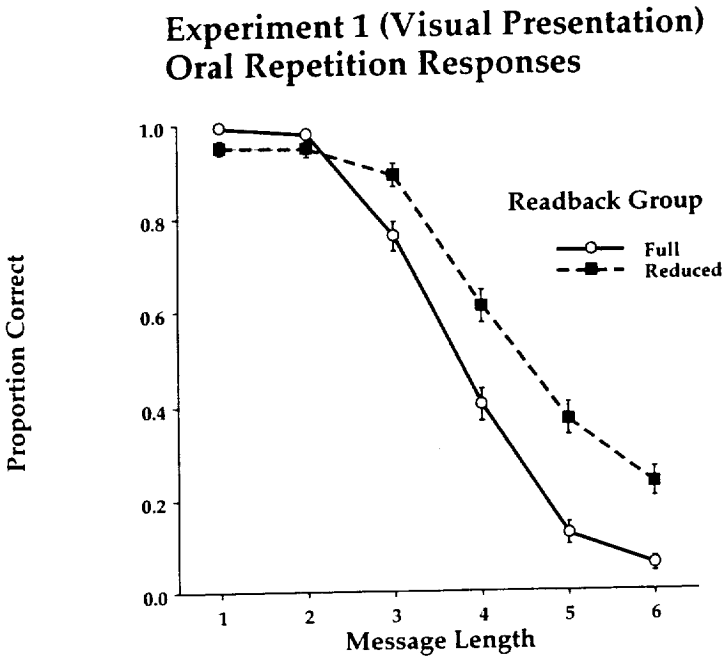
Between-Subjects Variables
- **presentation condition**
  - simultaneous
  - sequential
- **readback group**
  - full readback
  - reduced readback
  - no readback

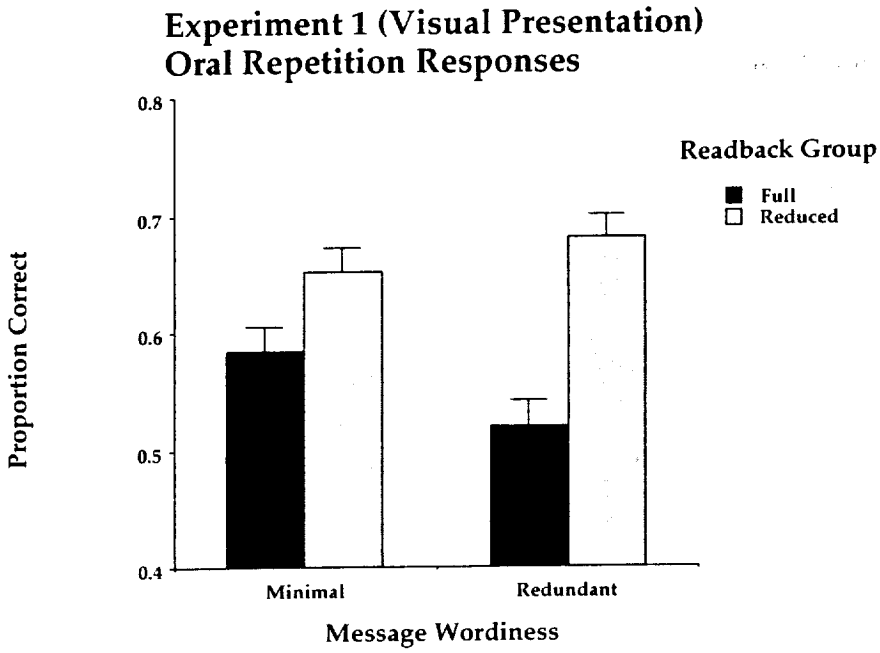
Within-Subjects Variables
- **message length**
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
- **command wordiness**
  - minimal--2 words
  - redundant--4 words

Dependent Measures
- **manual movement accuracy**
- **oral repetition accuracy**

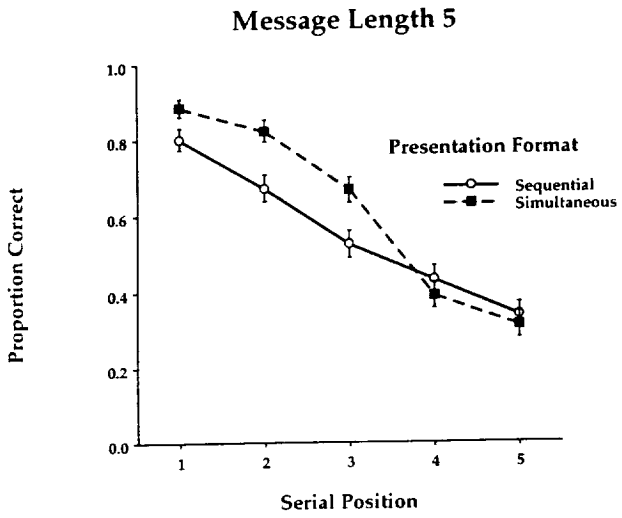

Experiment 1 (Visual Presentation)
Manual Movement Responses
Proportion Correct
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
Message Length
Readback Group
Full
Reduced
No

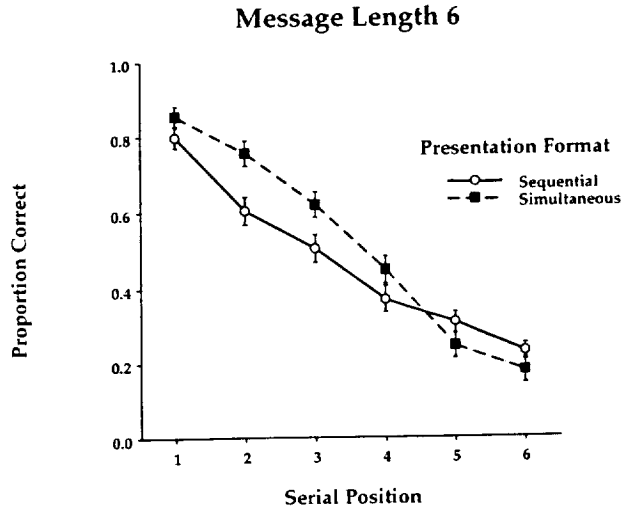

Experiment 1 (Visual Presentation)
Manual Movement Responses
Readback Group
Full
Reduced
No
Proportion Correct
0.7
0.6
0.5
0.4
Minimal
Redundant
Message Wordiness


Experiment 1 (Visual Presentation)
Oral Repetition Responses
Proportion Correct
1.0
0.8
0.6
0.4
0.2
0.0
Readback Group
Full
Reduced
1
2
3
4
5
6
Message Length

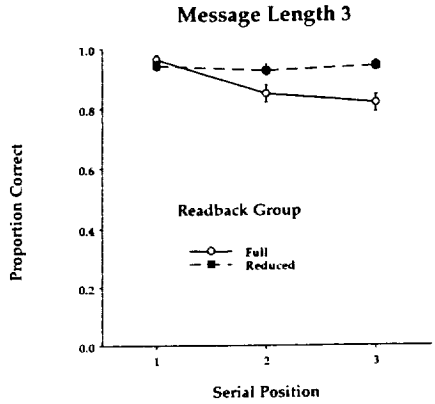

Experiment 1 (Visual Presentation)
Oral Repetition Responses
Proportion Correct
0.8
0.7
0.6
0.5
0.4
Readback Group
Full
Reduced
Minimal
Redundant
Message Wordiness

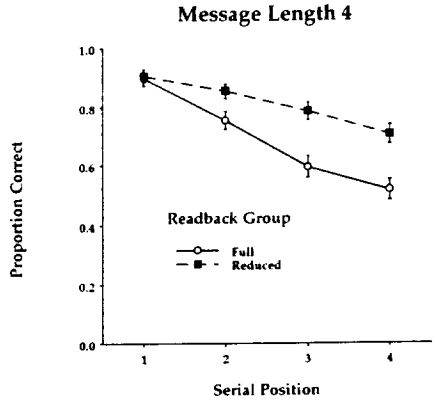
Experiment 1 (Visual Presentation)
Oral Repetition Responses

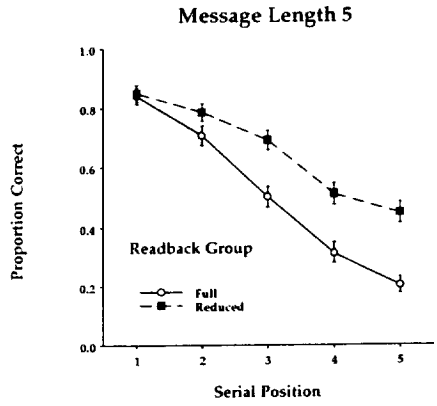




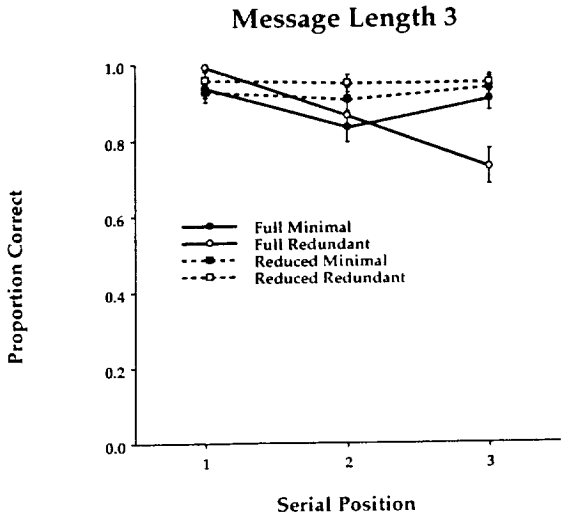
Experiment 1 (Visual Presentation)
Oral Repetition Responses

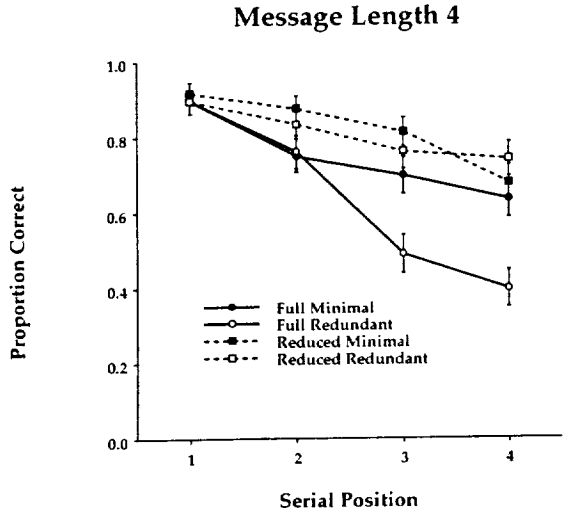






Experiment 1 (Visual Presentation)
Oral Repetition Responses





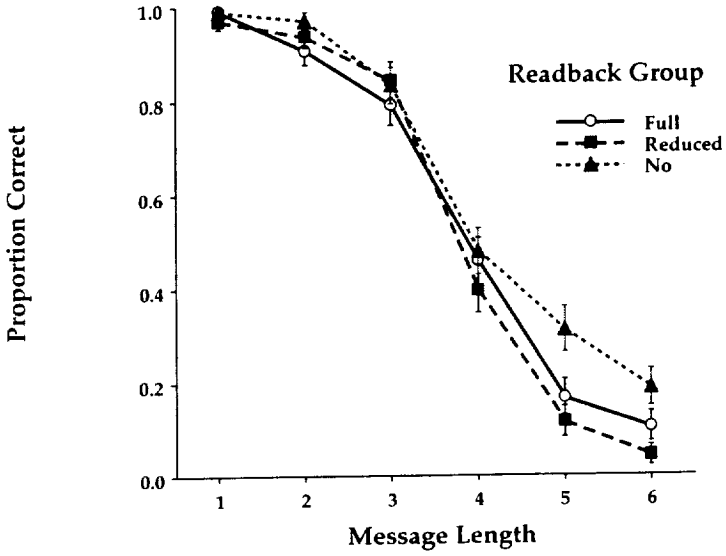
Experiment 2 (Auditory Presentation) Design

Between-Subjects Variable
- **readback group**
  - full readback
  - reduced readback
  - no readback

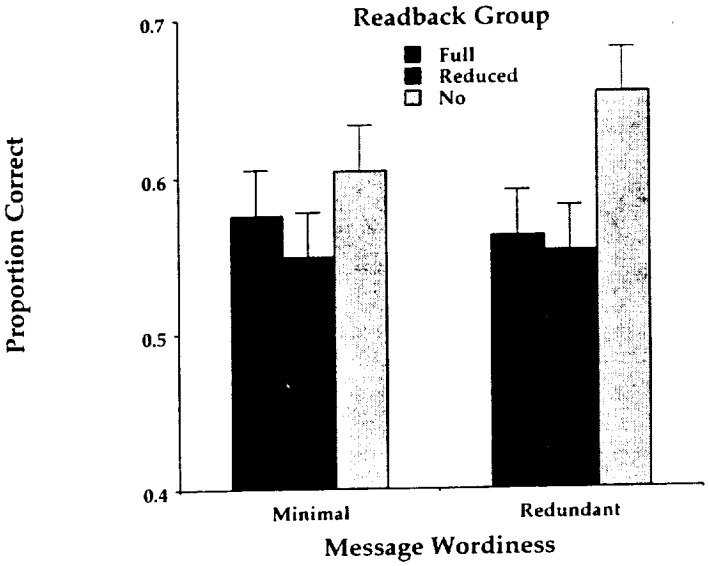
Within-Subjects Variables
- **message length**
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
- **command wordiness**
  - minimal--2 words
  - redundant--4 words

Dependent Measures
- **manual movement accuracy**
- **oral repetition accuracy**

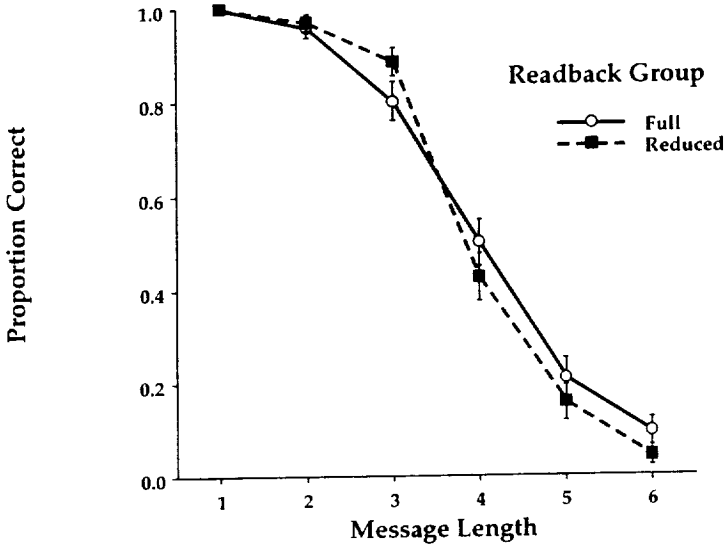
Experiment 2 (Auditory Presentation)
Manual Movement Responses



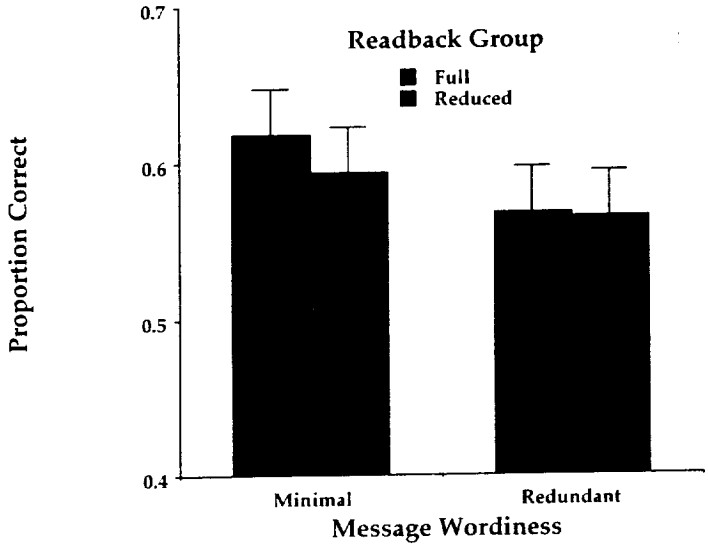
Experiment 2 (Auditory Presentation)
Manual Movement Responses

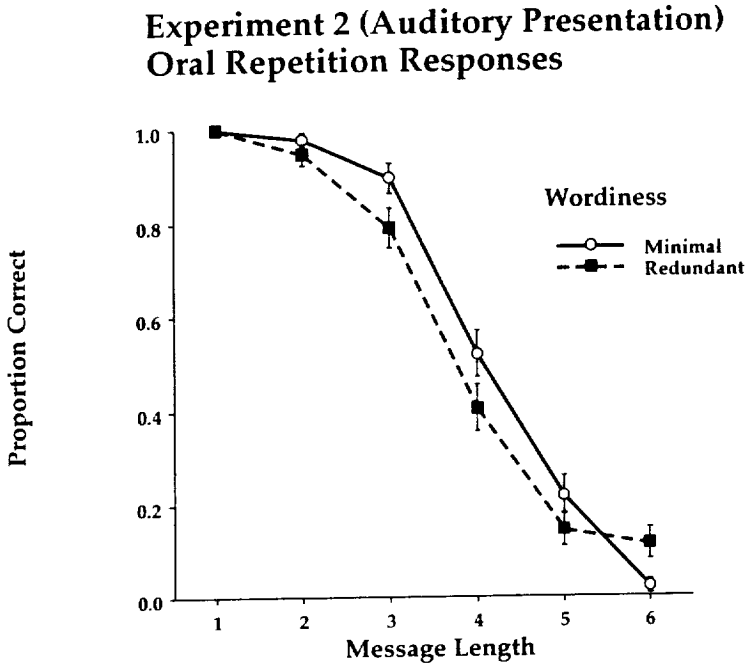


Experiment 2 (Auditory Presentation)
Oral Repetition Responses



Experiment 2 (Auditory Presentation)
Oral Repetition Responses




Experiment 2 (Auditory Presentation)
Oral Repetition Responses
Proportion Correct
1.0
0.8
0.6
0.4
0.2
0.0
1
2
3
4
5
6
Message Length
Wordiness
Minimal
Redundant

SUMMARY

Reduced readback

large facilitating effect for visual

no advantage for auditory

CONCLUSION

Advantage for reduced readback

due to visual scanning strategy

ignore unimportant words

RECOMMENDATION FOR VISUAL PRESENTATION

Reduce length of utterances in readback

CAVEAT FOR VISUAL PRESENTATION

If simultaneous commands

inadequate attention to later commands

RECOMMENDATION FOR BOTH MODALITIES

Limit navigational instructions to 3 commands